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VARIATIONS IN INTERNAL TEMPERATURE AND HEART RATE AS A FUNCTION OF METABOLISM AND ENVIRONMENT DURING POSITIVE AND NEGATIVE WORK

TRANSLATION OF "VARIATION DE LA TEMPERATURE INTERNE ET DU RYTHME CARIAQUE, EN FONCTION DU METABOLISME ET DE L'ENVIRONMENT, LORS DU TRAVAIL POSITIF ET NEGATIF", ARCH. SCI. PHYSIOL.; 1973, A 263-269

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16. Abstract

Equations are formulated for the relationships between rectal temperature, metabolism, ambient temperature and heart rate for both positive and negative physical work. When performing negative work, the cyclometer is powered by a motor and the subject brakes it with his legs. The equations were confirmed by measurements.

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VARIATIONS IN INTERNAL TEMPERATURE AND HEART RATE AS A FUNCTION OF METABOLISM AND ENVIRONMENT DURING POSITIVE AND NEGATIVE WORK

F.-A. Missenard*

1. Introduction

Some disagreement has arisen among physiologists over a body /A263** site suitable for taking internal temperature. Generally, this temperature is measured in the deep esophagus or in the rectum at a depth of about 20 cm.

These temperatures show minor differences during work with the legs on a cycloergometer. The variations in rectal temperature are about 15 percent greater than those of esophageal temperature. This elevation was sometimes explained by the relatively high temperature in venous blood coming from the legs.

The earlier physiologists [1] and [2] had studied this increase in internal temperature as a function of metabolism, without taking into account the personal power of the subject or his maximal /A264

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metabolism measured by his maximum consumption of oxygen (maximum oxygen uptake).

Some recent studies showed that the increase in internal temperature, for a particular increase in metabolism, is slightly variable from one subject to the other. Its value depends on the personal power of the subject, generally linked to his level of training.

Analytical studies of the experimental results show that the limit to the internal temperature which can be endured is reached at a lower metabolism when the maximum power of the subject is lower.

Whatever the case, in the following expressions, I have expressed the rectal temperature T_r, measured in °C, as a function of metabolism M, and of load H in W/m^2, and of ambient temperature T_a, measured in °C, the walls being at the same temperature as the practically motionless air.

II. Formulation of Equations

A. Positive work

The results below pertain to an average subject in good physical health, with minimal conditioning, in which the maximal consumption of oxygen is about 3.5 ℓ/min. For a height of 1.75 m and a body surface of 1.90 m^2, this corresponds to a maximum metabolism of about 620 W/m^2.

The previous results of Nielsen [1] and Winslow and Gagge (1941) [2], confirmed by the more recent results of Berggren and Christensen (1950) [3], Bodil and Marius Nielsen (1962) [4], Saltin and Hermansen (1966) [5], and Gagge and colleagues (1969 and 1970) [6, 7], allow us to express in °C the temperature of the deep rectum (Figure 1) by the following linear relationship, valid for metabolisms between 150 and 550 W/m^2, as a function of metabolism measured in W/m^2:

$$T_{re} = 36{,}8 + 0{,}42\frac{M}{100}\ ^{\circ}C$$

A remarkable thing is that this internal temperature is practically independent of ambient conditions between 0° and 30° C, within the limits of homeothermy. This independence has been verified in work of all types; in cyclo-ergometry, as well as on ski courses with a gradual ascent, in the course of which the ambient temperature varied from about 0 to 25° C.

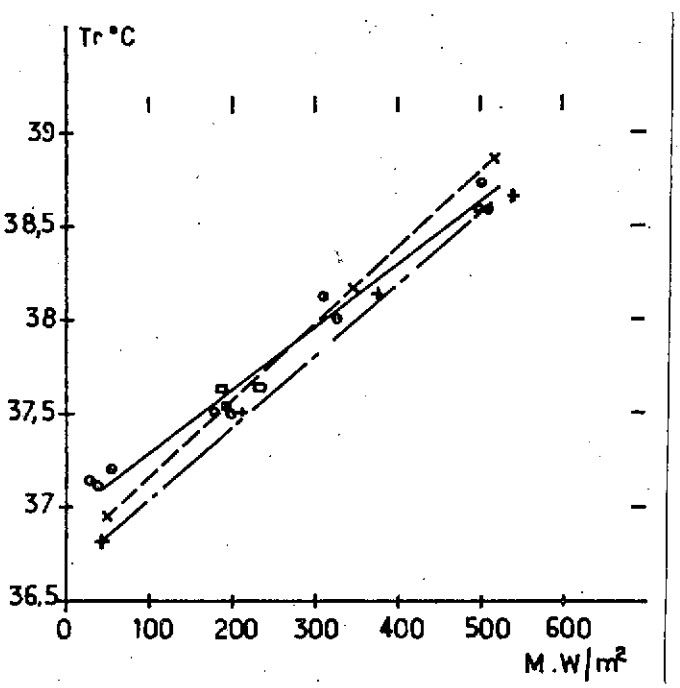
The coefficients of M relative to a mean subject, defined above, differ slightly from one subject to another. They can vary about 10 percent for the same degree of conditioning, and descend from 10 to 15 percent for extensive conditioning.

B. Negative work

For a long time, the experimental results concerned only positive work.

Very recently, some Nordic [8] and American [9] laboratories developed measures for positive and negative work.

In negative work, the cycloergometer is powered by a motor and the subject brakes it with his legs. The mechanical work of the motor W is thus absorbed by the muscles and, in order to maintain homeothermic equilibrium, the body must give off to the environment an amount



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Variation in rectal temperature as a function of total metabolism per square meter of skin surface:
o, + — studies by Gagge (1968); + — studies by Saltin (1966); × — studies by Nielsen (1938); □ — Winslow and Gagge (1941) (work on cyclo-ergometer)

of heat equal to its metabolism, increased by the caloric equivalent of work. Thus, in positive work, H = M - W; in negative work, H = M + W. /A266

Under the experimental conditions of these laboratories:

H = 0.8 M for positive work;
H = 1.8 M for negative work.

The critical analysis of the experimental results has allowed me to establish the following relationship for a minimally conditioned subject, as defined above, in expressing metabolism W/m^2 and internal temperature in °C:

— positive work: $T_{re} = 36{,}8 + 0{,}42 \frac{M}{100}$ °C;

— negative work: $T_{re} = 36{,}8 + 0{,}66 \frac{M}{100}$ °C.

For the same metabolism, the difference:

$$T_{re} = 0{,}66 \frac{M}{100} - 0{,}42 \frac{M}{100} = 0{,}24 \frac{M}{100}$$

corresponds to a difference in load of:

$$H = 1{,}8\ M - 0{,}8\ M = M$$

so that:

$$\Delta T_{re} = 0{,}24 \frac{\Delta H}{100}$$

which gives similarly for positive or negative work:

$$\boxed{T_{re} = 36{,}8 + 0{,}21 \frac{M}{100} + 0{,}24 \frac{H}{100}\ °C}$$

This expression is valid for positive or negative work by the legs on a cyclo-ergometer under the conditions previously specified and, in principle, with any means of mechanical delivery of work.

Thus, this resolves quantitatively the problem of the effect of a thermal charge due to work on the internal temperature, a question which for a number of years has been the object of discussions among physiologists.

But nothing proves a priori that the internal temperature rise is the same for a given thermal load caused by the surrounding medium (air temperature or increased diathermal radiation), because the heat is received by the surface instead of being dissipated in the muscles.

C. Heart rate

Previous studies had led me to use the following relationship to express heart rate HR in beats per minute during positive work with the legs on the cyclo-ergometer in an environment with stationary air and with wall and air temperature T_a: /A267

$$HR = 30 + 0{,}24\,M + 0{,}9\,T_a$$

This relationship was in good accord with those proposed by Metz and Vogt [9], as well as Vogt and colleagues [10].

Some recent studies by Nadel and colleagues [11] on positive and negative work on the cyclo-ergometer, have allowed me to express cardiac rhythm by the following expressions:

— positive work: $HR = 28 + 0{,}24\,M + 0{,}9\,T_a$;
— negative work: $HR = 21 + 0{,}39\,M + 0{,}9\,T_a$.

The increase in H when one passes from positive to negative work is accompanied by an increase in HR; from the figures of the authors, the following is obtained:

$$\Delta\,HR = 0{,}145\ \Delta\,H$$

As before, this allows us to express HR as a function of M and H for the two types of work, by the following relationship, which is valid for positive and negative work:

$$\boxed{HR = 24 + 0{,}13\,M + 0{,}145\,H + 0{,}9\,T_a}$$ beats/minute.

III. Conclusions

These relationships are in accord with my previous studies in that we can go from rectal temperature to metabolism in multiplying the coefficients of M and H by about 62. This shows that for the average subject, an elevation of 1° C in rectal temperature would be accompanied by a variation of 62 cycles/minute in cardiac rhythm. This seems to indicate that the subjects of Nadel are similar to the average subject of my previous studies.

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May I express a wish?

Because of recent studies and, in particular, those disclosed during this Symposium, our ideas — at least, mine — are beginning to become clearer.

I think that it would be possible and necessary to investigate /A268 systematically the effect of various thermal loads on the physiological factors characterized among others by:

— internal temperature; for instance, rectal temperature T_{re};
— heart rate HR;
— average skin temperature T_s.

Among thermal influences, it would be necessary to distinguish among:

— metabolism M;
— internal thermal load, H:
H = M - W, for positive work;
H = M + W, for negative work.

(However, H can also consist of an external source, such as diathermy, dissipating in the body.)

— external thermal load (R + C), due to radiation or to air temperature and wind action (see figure).

It would be interesting to investigate these effects within the established framework of homeothermy, as well as above and below homeothermy. Systematic work would allow us to improve our knowledge of the physiological reactions in these different cases.

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